
Chemical Contaminants in Human Milk: An Overview

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This review contains a succinct overview of the nature and extent of the problem of contamination of human milk with environmental and occupational chemicals, excluding drugs. Factors influencing the levels of contaminants in breast milk are discussed. Also, data on major chemicals of concern with potential health risk(s) to the general population and risk-benefit considerations are dealt with briefly. Based on the available data on the subject, research needs have been identified and policy recommendations are suggested. — *Environ Health Perspect* 103(Suppl 6):197–205 (1995)

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Introduction

In recent years, there has been a renewed interest in breast feeding; both medical and psychological studies have emphasized the considerable benefits of breast feeding infants. At present, about 65% of babies in the United States are breast fed when they are discharged from the hospital. The Canadian and American academies of pediatrics have published a position paper urging a return to breast feeding as the best nutrition for infants for the first 6 months of life (1).

With increased interest in breast feeding, there has been a parallel increase in concern over the excretion of drugs and environmental chemicals into breast milk and contaminants found in human milk. The following brief discussion on milk consumption and the diet of infants and children and the possible mechanisms of excretion of chemicals into breast milk is included to introduce the reader to the significance of the chemical excretion in human milk.

A number of studies demonstrate that the volume of milk intake among healthy, exclusively breast-fed infants ranges widely. After the first 4 to 5 months, the variance is even greater. For infants who were breast fed for at least 12 months and given solid foods beginning at 4 to 7 months, milk intake averaged 769 g/day (range, 335–1144 g/day) at 6 months, 637 g/day (range, 205–1185 g/day) at 9 months, and 445 g/day (range, 27–1154 g/day) at 12 months (2).

Milk intake is most often determined by weighing the infant before and after feeding. This method leads to underestimations of intake ranging from approximately 1 to 5% (3) because of water loss through evaporation from the infant between weighings. Newer techniques based on stable isotopes have been developed to measure breast-milk intake (4), but few data have been generated by this method to date. For a more detailed review of these data, see *Nutrition During Lactation* (5).

Milk predominates in the diet of 1- to 6-year-old children; the values for nonfat and fat milk solids are 30.4 and 13.4%, respectively. Any assessment of dietary exposures of nursing infants is complex. Human milk is the major food and source of essential nutrients consumed by infants during their first year of life, but a vast range of variables must be considered: the age at which supplementary foods are introduced, the selection of foods given to them, and the volume of human milk consumed. Factors greatly affecting the feeding patterns of infants include economic status; ethnic background; and the mother's nutrition, age, marital status, educational level, parity, and employment.

Infant formula is the sole source of food for nonnursing infants for the first 3 months of life. Milk or milk-based food remains the predominant source of energy and nutrients for all infants throughout their first year of life. Averaged over the first 12 months, nonfat and fat milk solids provide 44.2 and 10.4% energy, respectively, of their diet. The diets of infants and children are less diverse than those of adults. Caloric consumption by infants per unit of body weight is approximately 25 times higher for the very young infant (6) than that for adults. Therefore, comparing the consumption data for infants and adults on the basis of grams per kilogram of body weight results in an elevated value for infants. It is thus important to monitor both the percentage of total diet and the multiple of the national average consumption for each food and age group to identify areas relative to dietary exposure to pesticides and other environmental chemicals of concern.

The composition of human milk and its immunological properties provide significant advantages to human milk as the sole nutrient source in early infancy, even in industrially developing countries. However, in addition to the nutritional and immunological benefits of human milk, pediatricians and scientists have begun to recognize a wide range of chemical contaminants found in human milk and their potential adverse health effects on children.

The most widely recognized group of chemical contaminants are the fat-soluble, environmentally persistent organohalogen compounds such as dichlorodiphenyl-trichloroethane (DDT), polychlorinated biphenyls (PCBs), and dioxins. In

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addition, other contaminants such as heavy metals, pesticides other than DDT, and various organic solvents have been found in human milk.

This brief overview attempts to focus on the problem of environmental chemical contaminants (excluding drugs that are found in human milk), time trends in levels, factors influencing the levels of contaminants in breast milk, and associated adverse health effects in breast-fed infants. Finally, some research gaps are identified, together with recommendations for future work.

Recently, the American Academy of Pediatrics Committee on Drugs revised the list of agents (primarily drugs) transferred into human milk and described their possible known effects on the infant or on lactation (7). This review is not necessarily inclusive of all published literature, but it focuses on selected classes of environmental chemicals.

Pesticides in Human Milk

In general in the U.S. population, low levels of organochlorine pesticides are found in human tissues. These pesticides are fat soluble and bioaccumulate, and elimination from body fat stores is very slow. Excretion of these compounds via human milk exposes breast-feeding infants to a variety of organochlorine pesticides, especially in agricultural areas where they are most often used. Occupational exposure to organochlorine pesticides may occur during manufacturing, distribution, use in agriculture, recreation gardening, etc. Ongoing pesticide surveillance and the food residue level monitoring program by the Food and Drug Administration (FDA) indicate that pesticide concentrations in human milk continue to decline over time; however, data are difficult to interpret because the primary intent of the studies is for regulatory compliance and enforcement. Although data on pesticide residues in food are extensive and infant formulas and processed baby foods are routinely monitored to ascertain pesticide residue levels, many uncertainties exist with regard to uniformity of sampling, analytical techniques, quality control, etc., thus raising questions about the usefulness of the data in actual risk estimations. In general, due to the decreasing use of this class of pesticides in the United States and other countries, declining concentrations in human milk have been observed. Potential adverse health effects due to low-level exposure in developing infants and children are unknown.

As stated earlier, many of these lipid-soluble compounds bioaccumulate and are not cleared rapidly. Human milk is one route of elimination for the mother's body burden, but unfortunately that route also increases the exposure of infants (8). There have been many surveys of pesticides in human milk—some in response to episodes of food or dairy product contamination. The data from these surveys have been used to compare pesticide concentrations in human milk to establish allowable daily intakes.

In general, the more recent surveys of pesticides in human milk have demonstrated that the concentrations are lower than those observed in previous surveys. Despite this decrease in concentrations, more effort is needed to characterize the potential adverse effects of the low concentrations of chlorinated pesticides found in human milk. Initial attempts at estimating such effects associated with low concentrations have recently been described by Mattison (9–11) and Rogan et al. (12).

DDT and Its Metabolites

DDT has a long history of use worldwide as an effective pesticide for controlling mosquitoes and other pests. Concern over reproductive effects of DDT and its metabolite dichlorodiphenyldichloroethylene (DDE) in birds and its long biological persistence led to the cessation of DDT use in the United States approximately 20 years ago. Despite the ban, this pesticide and its metabolites continue to be found in human milk in the United States at decreasing concentrations over time, demonstrating the remarkable biological persistence. The range of means of *p,p'*-DDT and *p,p'*-DDE reported in surveys of human milk in the United States before 1986 varied from 0.2 to 4.3 ppm and 1.2 to 14.7 ppm in milk fat, respectively. The mean concentrations among quantifiable samples from the 1986 survey in Arkansas were at the low end of these means. Among all samples, the mean concentrations were considerably lower than those previously reported. The mean concentration of *p,p'*-DDT in all samples assayed in Arkansas was 0.039 ppm; the highest quantified level was 0.203 ppm (13). Among those with quantifiable concentrations, the mean was 0.954 ppm. This appears to show a continued decrease in DDT concentrations in human milk over the years.

In developing countries DDT and its metabolites are often the most widespread

contaminants in human milk, found as *p,p'*-DDT and *p,p'*-DDE. In general, DDT levels are relatively high in developing countries where DDT still is, or until recently has been, used extensively in agriculture and public health (14). Typical average background levels are now around 30 ppb total DDT in whole milk and 1 ppm in milk fat. In developing countries, levels 10 to 100 times higher may still be found in some areas. There are obviously large differences in levels in human milk between countries and regions of developed countries; these levels are directly related to the recent use of DDT. Women immigrants from developing countries often have far more DDT in their breast milk than women in the local population of developed countries (15).

Dieldrin, Aldrin, and Endrin

These are very persistent insecticides that have been banned in the United States, but they remain in use in some developing countries (16). Dieldrin is a metabolite of aldrin that persists in adipose tissue. Previous surveys conducted in the United States have identified detectable levels in 0.04 to 100% of the human milk samples analyzed (8). Mean dieldrin concentrations ranged from 0.05 ppm to 0.24 ppm in milk fat (8). The mean concentration in 2% of Arkansas samples with quantifiable levels was 0.071 ppm. Recently, high levels of dieldrin have been detected in milk samples from the Middle East, South America, and Australia (17,18). Aldrin and endrin have been occasionally reported in human milk.

Lindane

Lindane is a mixture of various isomers of hexachlorocyclohexanes (HCH) and has been used as a substitute for DDT. In previous surveys conducted in the United States, HCH isomers were found in quantifiable concentrations in 4 to 68% of the human milk samples analyzed (8). For example, the β -HCH isomer was found in 27% of the human milk samples tested from Arkansas women (13). Among those with quantifiable levels, the mean concentration was 0.12 ppm, and among all samples, the concentration was 0.03 ppm. Lindane's agricultural uses in the United States have been virtually eliminated by changes in regulations over the past 20 years. The recent levels of HCH isomers reported for most European countries are generally low (average 0.2 ppm in fat) compared with those reported from Asia,

especially India and the People's Republic of China (average 6 ppm in fat).

Hexachlorobenzene

Hexachlorobenzene (HCB) is a persistent chemical with a variety of sources, including its previous use as a pesticide and its presence as an impurity in several other pesticide formulations. This compound can disrupt porphyrin metabolism (8). Fatal cases of infant poisoning from ingestion of highly contaminated human milk have been reported. Because of persistence and solubility, hexachlorobenzene has been detected in many surveys of adipose tissues in the United States; few studies have explored the presence of this chemical in human milk. Among previous surveys conducted in the United States, the mean concentration was 0.04 ppm in milk fat (range, 0.018–0.063). Among the 6% with quantifiable levels in Arkansas, the mean was 0.03 ppm; and among all samples, the mean concentration was 0.002 ppm; both are lower than in earlier reports (8). Hexachlorobenzene is no longer registered for agricultural use, and its occurrence as a formulation impurity in other registered products has been greatly curtailed.

In the late 1950s, about 500 people were fatally mass intoxicated in Turkey and about 4000 became sick from eating breads made from HCB-treated wheat. HCB contamination caused skin lesions due to altered porphyrin metabolism. Children under 2 years of age who were breast fed by mothers exposed to HCB died of the condition known as "pembe yara" (pink sore). Elevated levels of HCB in human milk were still observed in the area 20 to 30 years after the accident (19,20).

Cyclodiene Pesticides

Heptachlor, chlordane, and their metabolites (heptachlor epoxide, oxychlordane, *trans*-nonachlor) are closely related cyclodiene pesticides. Surveys conducted in the United States have demonstrated that between 25 and 100% of human milk samples analyzed had quantifiable concentrations of heptachlor or heptachlor epoxide ranging from 0.035 to 0.13 ppm (8). A somewhat greater proportion of samples (46–100%) had quantifiable concentrations of chlordane and oxychlordane (range, 0.05–0.12 ppm), perhaps reflecting frequent use as a termiticide in houses (16). Among samples surveyed in Arkansas, 5% had quantifiable concentrations of heptachlor (mean, 0.03 ppm) and 74% had quantifiable concentrations of heptachlor

epoxide (mean, 0.06 ppm) (13). Two percent of the samples in that study contained quantifiable concentrations of chlordane; 77 and 84% had quantifiable concentrations of *trans*-nonachlor and oxychlordane, respectively. The mean concentrations among quantifiable samples measured in Arkansas for *trans*-chlordane, *cis*-chlordane, and oxychlordane were 0.18, 0.15, and 0.06 ppm in milk fat, respectively. In most studies, heptachlor and heptachlor epoxide were also detected in human adipose tissue samples (21,22).

One study of approximately 1500 women (23) explored regional differences in the pesticide content of human milk. In the southeast region of the United States, including Arkansas, 76% of the samples tested had detectable levels of heptachlor epoxide. The distribution of heptachlor epoxide concentrations in samples was also higher in the southeast region. Only 23% of the samples tested contained trace or undetectable concentrations. Half of the samples (52%) had heptachlor epoxide concentrations ranging from 0.001 ppm to 0.1 ppm. The remainder (approximately 25%) contained concentrations above 0.1 ppm. This was the highest concentration among all regions in the United States. The mean concentration of heptachlor epoxide in these samples with detectable levels was 0.128 ± 0.209 ppm, which also was the highest mean level for all the regions surveyed in the United States.

Similar studies of human milk in Pennsylvania (24) and in Missouri (25) have demonstrated mean heptachlor epoxide concentrations of 0.16 and 0.0027 ppm, respectively. Studies conducted in Hawaii (26,27), where inhabitants have also been exposed to heptachlor and heptachlor epoxide in dairy products, have demonstrated levels ranging from 0.001 to 0.067 ppm (mean 0.036 ppm) among women on Oahu, and from 0.015 to 0.052 ppm (mean 0.031 ppm) among women on neighboring islands.

With the exception of endosulfan, which does not exhibit the persistence and bioconcentration characteristics of other chemicals in the group, virtually all agricultural uses of the cyclodiene pesticides have been eliminated or greatly restricted by regulatory actions over the past 20 years.

Other Persistent Organohalogenes

Dioxins and Dibenzofurans

Chlorinated dioxins and dibenzofurans are

highly toxic chemicals derived from commercial sources such as 2,4,5-T and pentachlorophenol found in hazardous waste sites and bleaching paper or generated during industrial processes (e.g., incineration of municipal waste and combustion of leaded gasoline). The main source of exposure to these compounds is food, especially meat, dairy products, and fish (oil). Inhalation is only a minor source of exposure. Dioxins have been detected in human milk at relatively high concentrations (28–31). Dioxins are very lipophilic and are mainly stored in adipose tissue (32–34). The concentration of dioxins in breast milk decreases with duration of lactation and with the number of breast-fed children (30). A recent study indicates that dioxin exposure of the breast-fed infant is very high and exceeds the accepted daily intake more than 20-fold at the age of 4 weeks (31). It was estimated that daily intake from milk of a cow grazing in the neighborhood of an incinerator was about 200 times the intake by inhalation of the ambient air (35). The bioavailability of dioxins and dibenzofurans from breast milk is high, and no obvious change in fecal excretion of dioxins with age was found. Furthermore, no effects of dioxin exposure could be observed on physical and neurological development of the breast-fed infant. However, several clinical laboratory parameters were affected on dioxin exposure.

Polychlorinated Biphenyls

Polychlorinated biphenyls are produced as technical mixtures with different degrees of chlorination—usually with a chlorine content between 40 and 60% (e.g., Aroclor 1242 and 1260).

In 1968, a serious mass intoxication occurred in Japan from a large-scale PCB contamination of rice-bran oil due to a leak in a heat transfer installation. More than 1700 people became ill and about 20 died. The main symptoms of this so-called "Yusho disease" were severe dermatological abnormalities, including chloracne (36). Infants born to women in Yusho had abnormally dark brown skin and other abnormalities. The average PCB concentration in whole blood from Yusho patients at the time of the incident was about 60 ppm; the concentration of PCBs in Yusho milk fat may have been more than 10 ppm (37,38).

A similar mass poisoning, called Yu-Chen, occurred in Taiwan in 1979, with more than 2000 identified victims. It is

now accepted that polychlorinated dibenzofurans, which were present as impurities in the used PCB liquid, were the major etiologic factor (39).

PCBs are widely distributed in human milk from industrialized countries, but PCB levels are mostly below the detection limit in milk from Third World countries. The average concentrations of total PCBs in human milk fat are typically between 0.5 and 2 ppm, depending on the place of sampling and the analytical methods used.

In a Canadian study, the highest level of PCBs (4.3 ppm) was found in milk fat from a mother who had lived in an industrialized area close to a municipal incinerator for 5 years (40). Occasionally, extremely high levels of PCBs (<10 ppm) in human milk fat have been found in lactating women living at farms where the silos have been treated with PCB-containing paints (41). In many industrialized countries, women immigrants from less-developed countries often have far more DDT and less PCBs in their breast milk than native citizens. Of the 209 PCB congeners, about a dozen can be separated in human milk by the most common analytical methods. In general, relatively more of the higher chlorinated congeners are found in human milk. However, the pattern of chlorine substitution is also important.

At present, there is no universally accepted procedure for determining the total PCB content of human tissue samples. In fact, the average background levels of PCBs in human milk do not differ very much between industrialized countries if the quantitation procedures are nearly the same. Typical average levels are 0.5 to 1.5 ppm PCBs in extractable fat. The difficulties in investigating trends are illustrated by Rogan et al. (12,43). They found somewhat higher PCB levels in milk fat than those previously reported in the United States by Schwarz et al. (44), and these differences may be explained by analytical approaches.

Polychlorinated Terphenyls

The chemical and biological properties of polychlorinated terphenyls (PCTs) are closely related to those of PCBs. PCTs have only been found in human milk samples from Japan (45). The average level of PCTs in human milk fat was about 0.02 ppm; this corresponds to 1/60 of that of PCBs in the same sample. In contrast to the situation with PCBs, the levels of PCTs in milk fat were significantly lower than those found in adipose tissue. PCTs were

not detected in human milk from Canada (46). In Europe, PCTs have not been investigated in human milk, but PCTs were found some years ago in two adipose tissue samples (0.5–0.8 ppm) from the Netherlands (47).

Polybrominated Biphenyls

The hazards of polybrominated biphenyls (PBBs) were discovered after the pollution episode in Michigan in 1973. Animal feeds were accidentally contaminated with Fire Master BP-6—a mixture of PBBs mainly consisting of hexabromobiphenyls, which were normally used as a flame retardant in polymers. Later, PBBs were detected widely in domestic animals, foodstuffs, and human tissues. Although no acute or chronic effects of PBBs have been identified in humans, the possibility of long-term effects cannot be ruled out (48).

Most of Michigan's inhabitants received measurable quantities of PBBs in their body tissues. In 1976, 96% of 53 samples and 43% of 12 samples of human milk from two areas of Michigan contained 0.01 to 1.2 ppm PBBs on a fat basis. The median value was 0.068 ppm (49). In a larger investigation of 2986 breast milk samples obtained between May 1976 and December 1978 from all of Michigan, PBBs were detectable in 88% of the samples. The maximum level in milk fat was 2 ppm, and the mean and median were 0.1 ppm and 0.06 ppm, respectively (50). In breast milk fat from 32 directly exposed women farmers, a mean value of 3.6 ppm PBBs, with a maximum of 92 ppm, was detected. The mean ratio of milk to serum PBB values in 21 individual women showing detectable levels was 122:1, while the mean ratio of adipose fat to serum PBB was 362:1 (51,52). Weil et al. (53) reported that 42% of the PBB-exposed women breast fed their children compared with 85% of controls. Furthermore, the duration of breast feeding was longer among the controls (mean, 29.6 weeks) than among the PBB-exposed women (14.8 weeks). Some preliminary results suggest the existence of an inverse relationship between body levels of PBBs and some developmental effects in 2- to 4-year-old children (54). In May 1974, a PBB tolerance of 1 ppm in human milk fat was established, but in November of the same year it was reduced to 0.3 ppm (55).

A more recent study on lactating women concludes that PBBs are very persistent, and no significant decrease has been found in the levels in the population

during a decade; it was estimated that 47% of all breast milk samples would still have detectable levels of PBBs by the year 2000 (50). PBBs have not been reported in human milk from outside Michigan, e.g., in a survey in 1977 to 1978 in Alberta, Canada (56).

Other Organohalogenes

Chlorobenzenes

Several chlorobenzenes were detected in human milk (57). The most abundant was *p*-dichlorobenzene (58). The sources of these chlorobenzenes have not been identified, but it is known that *o*-dichlorobenzene is used as a bactericide, and *p*-dichlorobenzene is used in mothballs and as a deodorant in toilets. Other chlorobenzenes are chemical intermediates or contaminants in commercial chemicals, e.g., pentachlorobenzene is an impurity in and a degradation product of hexachlorobenzene, indicating a potential for a wider occurrence in human milk.

Pentachlorophenol

In recent investigations, trace amounts of pentachlorophenol (PCP) were detected in human milk. Free PCP has also been found in human adipose tissue at levels from 4 to 250 ppb, together with its palmitic acid ester (59). This ester may also be present in human milk, but this has never been investigated. Pentachlorophenol is an important wood preservative in many countries.

Mirex

Mirex is a persistent, fully chlorinated, cyclic hydrocarbon. Until 1978, it was widely used as a pesticide for fire ant control in the southeastern United States and also as a flame retardant. The use of mirex as a pesticide caused contamination of cattle milk (60), and considerable mirex pollution was discovered some years ago in Lake Ontario (61). A few investigations have indicated the occurrence of traces of mirex in human milk from North America (46,62).

Toxaphene

The pesticide toxaphene is a mixture of polychlorinated terpenes. It is a global pollutant spread by long-range air transportation. Although the pesticide has hardly been used, it was detected in wildlife and in two pooled human milk samples from Sweden. The toxaphene level calculated was 0.1 ppm in milk fat (63).

Chloroethers

Bis(2,3,3,3-tetrachloropropyl)ether, which is used in Japan as a synergist in pyrethrum insecticides for mosquitoes, has been detected in human milk (64).

Polychlorinated Naphthalenes

Polychlorinated naphthalenes (PCNs) are used as insulating materials for cables and in lubricants. In a recent investigation PCNs were detected in human milk from Los Angeles and Sweden. The concentrations were between 1.7 and 3 ppb PCNs in milk fat (65).

Nonhalogenated Organic Compounds

Most nonhalogenated organic chemicals are not very persistent, either in the environment or in the human body. Thus, detectable levels of such substances in human milk are usually found when the exposure is high and long-term in nature, as in the occupational environment.

Organophosphates

In Taiwan, extremely high levels of malathion were found in human blood and breast milk samples from 1974 to 1975. The average malathion level in 12 milk samples was 1.88 ppm in whole milk (66). Furthermore, 0.1 ppm of another organophosphate pesticide, dimethyl-dichlor-vinyl phosphate (DDVP), was found in a single sample. In nine human milk samples from women living in the Santa Clara Valley of California, an area repeatedly sprayed with malathion, no malathion could be detected in any of the milk samples. The detection limit was <5 ppb in whole milk (67).

Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are emitted on heating or burning of organic matter, including food. In 10 German breast milk samples, 14 PAH components were detected, including the carcinogens benz[*a*]anthracene and benzo[*a*]pyrene. The average total level was 0.1 ppb in whole milk (68).

Nitrosamines

In a recent investigation of 51 milk samples from 13 nursing mothers in the United States, 16 samples contained measurable levels (0.1–1.1 ppb) of *N*-nitroso-dimethylamine. In certain individuals, eating a meal of bacon and a vegetable high in nitrate occasionally resulted in higher levels of nitrosoamine in their milk (69).

Nicotine

Recently it was discovered that passive smoking may result in measurable nicotine concentrations (mean about 12 ppb) in breast milk (70).

Heavy Metals

Breast milk normally contains trace levels of most metals and other elements. Both inorganic and organic compounds of the metals are found in human milk, but not associated with milk fat. The processes by which the metals are excreted through the mammary glands are not fully known, but they are probably different from those for the lipophilic organohalogenes.

In risk evaluations, it has to be borne in mind that the absorption of heavy metals in infants is generally higher when they are on a milk diet, probably due to binding to readily absorbed milk proteins.

Lead

At present, average background levels of lead in human milk from industrialized countries are probably between 5 and 20 ppb. In heavily polluted areas they may be up to 20 times higher (71). Directly toxic levels have been seen in occupational settings or in lead poisoning cases (72). Lead in milk is better absorbed into the body than lead present in other dietary components. Lead levels in breast milk are normally lower than lead levels in milk-based infant formulas (73). Lamm and Rosen (74) noted higher blood lead levels in formula-fed infants than in breast-fed infants.

Cadmium

Fewer investigations have been carried out on cadmium in human milk, and the reported levels vary widely. Average background levels seem to be <2 ppb (µg/l), although levels 10 times higher are often quoted. Cadmium levels in human milk correspond to those in cow's milk (75). Compared to other foods, cadmium in milk seems to be more bioavailable and it concentrates more in the kidneys (76). In cows, cadmium in the feed has been shown to decrease milk production (72).

Mercury

The levels of mercury in human milk are typically lower than those of lead and cadmium. Average background levels are <1 ppb (µg/l). The highest levels were detected in milk from fish eaters, and about 20% of the total mercury content was in the form of the more toxic methyl mercury (77).

During pollution episodes in Japan, such as the outbreak of Minamata disease, mercury levels of about 50 ppb in human milk were found (78). With the tragic mercury poisoning in Iraq in 1972 due to ingestion of homemade bread prepared from wheat treated with a methylmercury fungicide, the predominant route of infant intake of mercury was via breast milk. The mercury content in human milk was reported to be up to around 200 ppb, and about 60% was methyl mercury (79).

Other Metals and Trace Elements

Numerous studies on the presence of metals and trace elements in human milk have been published. Most are difficult to compare because of the use of different analytical techniques and the lack of adequate quality assurance (80). However, for several of these trace elements, the data base is very limited to ascertain risk to infants. Occupational exposure to these elements may result in much higher and even toxic levels in breast milk.

Considerations of Specific Subpopulations

Certain populations of infants and children may be more sensitive to the effects of chemical exposure through breast feeding because of physiological and biochemical factors such as genetic predisposition, chronic medical conditions, interactions of chemicals with medications, nutritional status of mother, and general health status. Other factors that may make certain infants and children more susceptible include increased exposure through farm work or parental occupational exposure and low socioeconomic status.

Children living in poverty may constitute an additional sensitive population. One factor contributing to compromised health status is poor nutrition. Preschool children of low socioeconomic status have been found to have lower dietary intakes, lower biochemical indices, and smaller physical size for their age than children of higher socioeconomic status. Because of compromised health status, infants and children of low socioeconomic status are probably more susceptible to any toxic insult, including chemical exposure. Infants and children of poor families are more likely to live in highly polluted neighborhoods and thus have greater exposure to environmental toxicants. Therefore, one might expect that adverse effects of chemicals, whether acute or chronic, might be magnified in this subpopulation.

Uncertainties in Risks to Infants from Chemicals in Human Milk

Breast feeding has substantial benefit, including psychological, immunological, and general health promotion. In many countries, breast feeding confers measurable benefits such as decreased rates of infectious disease and increased rates of growth and development. Despite the concentrations of chemicals found in human milk, no major studies have demonstrated that these chemical concentrations have led to adverse health outcomes in the children exposed through breast feeding, with some exceptions as pointed out earlier. Therefore, although there is concern that exposure to chemicals in human milk may carry some potential for adverse health effects for the mother and for the nursing infant, it is important to recognize the benefits of breast feeding. Furthermore, surveys conducted in the United States over the past four decades have shown that the number of samples with detectable chemical concentrations has been falling—even when improved analytical methods with increased sensitivity have been used.

The FDA monitors certain pesticide residues in all food other than meat, milk, and eggs. The FDA's monitoring program is not designed to determine dietary exposure to all pesticides or to other chemicals of concern; rather, its objectives are to enforce compliance with U.S. EPA tolerance levels.

It is also important to recognize the wide variation in sampling and analytical methods, size, overall design, and objectives of existing residue testing programs. The most comprehensive and best recorded data on pesticides are those collected through FDA's market basket sampling survey and analysis, but no single data bank provides ideal residue values for other toxic chemicals. Chemical residue analyses are complex, difficult to perform, and expensive. All data should be judged within this perspective. Methods for uniform sampling, collection, and reporting to reflect the adequacy of the data's quality are needed.

Fat-soluble chemicals, such as chlorinated halogens, heavy metals, and organic solvents, are excreted in human milk. It is evident that human milk is contaminated with organic and inorganic chemicals in the environment, and exposure can occur to breast-feeding infants through mother's milk and other food sources. However, no overt clinical illness has occurred in infants

from such exposures except in cases of accidental poisoning outbreaks. It is not clear whether overall *in utero* or lactational exposure of the mother has an impact on the body burden of infants. Furthermore, the contribution of chemical contamination in human milk, compared with dietary intake other than through mother's milk, and its potential impact on adverse toxicological effects are unknown, and no adequate evaluation has been conducted for most chemicals. Current risk assessment methods generally do not make specific allowances for chemical exposures via mother's milk to infants and children. Species conversion of dietary intakes per unit of body weight is normally based on adult body weights and food consumption data.

Lactating women may be exposed to lipophilic chemicals from various sources, including air, food, water, cosmetics, and occupational and household environments; and they may have substantial stores of some chemicals that can be mobilized during lactation. Within a few months of birth, the concentration of organochlorine compounds in the body fat of the breast-fed infant may be equivalent to that in the fat of the lactating mother. Although the period of breast feeding is short compared to the total life span, the lipophilic chemicals accumulated in the body during these early months may be retained for years.

Another source of exposure to chemicals is drinking water and water used for mixing milk formulas. Although water intake is considered, neither nondietary exposures nor exposures in drinking water are considered in deriving risk estimates for total chemical exposure in infants' milk. Because of this limitation, total exposures of infants and children may be underestimated.

Conclusions

The evaluation of potential risks to infants and children due to chemical residues present in human milk and diet requires consideration of a number of factors. In particular, the level of risk depends on each individual's food consumption patterns, nature and levels of chemical residues in milk and other food as consumed by lactating mothers and breast-fed infants and children, and their toxicological potency. A comprehensive analysis of the potential health risks to infants and children exposed to chemicals in their milk and diets requires consideration of all these factors as well as any unique characteristics of infants and children relative to adults. In addition, it is known that socioeconomic,

nutritional, and health status influence the vulnerability of human infants and children to environmental toxicants and should be accounted for in an estimation of health risks.

Infants and children may exhibit unique susceptibility to the toxic effects of chemicals because they are undergoing rapid tissue growth and development, but empirical evidence to support this is mixed. Infants and children also consume much greater quantities of milk fat and certain foods than do adults on a body weight basis and thus may be subjected to higher levels of exposure to certain chemicals than adults. These exposures occurring earlier in life can predispose infants and children to a greater or a lower risk of chronic toxic effects than exposures occurring later in life. Therefore, traditional approaches to toxicological risk assessment may not always adequately protect infants and children.

Although current uncertainty factors used to extrapolate toxicological data to humans account for 10-fold variations between species and within the human population, additional protection may be required as justified, depending on the toxicant of interest and the amount of dietary residue monitoring and testing that has been conducted. It must be recognized that there exist only limited data on the residue levels of chemicals in milk and food consumption patterns of infants and children that are appropriate for use in risk assessment.

Recommendations

- Additional data are needed on the chemical contaminants in mother's milk and other foods and food consumption patterns of infants and children. Current data indicate that infants and children consume significantly greater amounts of milk and certain foods on a body weight basis than adults do. Because such higher exposures can lead to higher risks, it is important to have accurate data on the chemical contaminants in the milk and food consumption patterns of infants and children. The available data are based on relatively small samples and may not reflect current trends in food consumption by infants and children. A centralized data base for chemical residue data and standardized analytical procedures may be needed to improve the ability to characterize chemical exposures.

- All sources of exposure to chemicals—dietary and nondietary—need to be considered when evaluating the potential risks to infants and children. The total intake from all sources of foods on which residue may be present should be calculated when estimating exposure of infants and children. Chemicals also may be present in drinking water and water used in preparing milk formula due to contamination of sources of water.
- Physiological and biochemical characteristics of infants and children that influence pharmacokinetics of xenobiotics need to be considered in risk assessment. Physiological parameters such as tissue growth rates and biochemical parameters such as enzyme induction may affect the response of infants and children to chemical residues in milk, milk products, and other foods. Pharmacokinetic models that provide for the unique physiologic characteristics of infants and children should be developed.
- There is a need for validated animal models for predicting the risks of chemical contaminants in milk to infants and children.

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